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Comparison of Electrostatic Precipitator Performance with Pulse and DC Energization

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16. ABSTRACT The paper compares electrostatic precipitator (ESP) performance with pulse and dc energization. Pulse power for ESPs has been offered as a possible solution to the problems associated with collecting dust with high electrical resistivity in ESPs. Data have been presented to show a dramatic improvement in ESP performance for pulse vs. dc power supply. Because pulse power appeared to have significant performance advantages over dc, EPA conducted an investigation of pulse power. As part of this investigation, an experimental program was developed to investigate pulse power. In addition to pilot plant tests, EPA participated in a field evaluation of pulse energization of a hot-side ESP. Results of these experiments are discussed in the paper, along with an economic analysis of pulse power. The main advantage of using pulse power supplies is that good control of the electrical operating conditions of the ESP is possible, even when dusts with high electrical resistivity are being collected. Such good control is often not possible with dc. The value of good control should not be neglected: that pulsing permits control of the operation of an ESP is significant.

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Pulse Modulation	Pulsed Power	13I
Direct Current	Particulate	20N
Dust		20C
Particles		11G
Electrical Resistivity		

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Introduction

Pulse power for electrostatic precipitators (ESPs) has been offered as a possible solution to the problems associated with collecting dust with high electrical resistivity in ESPs. Lausen (1) and others have presented data to show a dramatic improvement in ESP performance for pulse versus dc power supply.

Because pulse power appeared to have significant performance advantages over dc, EPA conducted an investigation of pulse power. As part of this investigation, an experimental program was developed to investigate pulse power in cooperation with Denver Research Institute. Denver Research designed and built the pulse power supplies and then delivered them to the Particulate Technology Branch of EPA's Industrial Environmental Research Laboratory at Research Triangle Park, N. C. (IERL-RTP). All of the experiments were conducted in the IERL-RTP in-house ESP.

In addition to the pilot plant tests, EPA participated with the Electric Power Research Institute and Southern Company in a field evaluation of pulse energization of a hot-side ESP.

The results of these experiments will be discussed in this paper along with an economic analysis of pulse power.

Experimental Equipment

The pilot plant experiments were conducted in a single-lane pilot plant ESP at IERL-RTP. The ESP has been completely described by Lawless et al. (2), so only a brief description will be given here.

A sketch of the ESP is shown in Figure 1. The ESP is a single-lane, four-electrical section, ESP. For these experiments, sections 1 and 2 and 3 and 4 were electrically connected, so that only two power supplies were needed to energize the ESP.

The pulse power supply was designed and constructed by Denver Research Institute. The pulse height and pulse rate were adjustable from 0 to about 50 kV and from 0 to about 110 pulses per second. The pulse width was about 100 μsec. A plot showing the pulse shape and width is shown in Figure 2.

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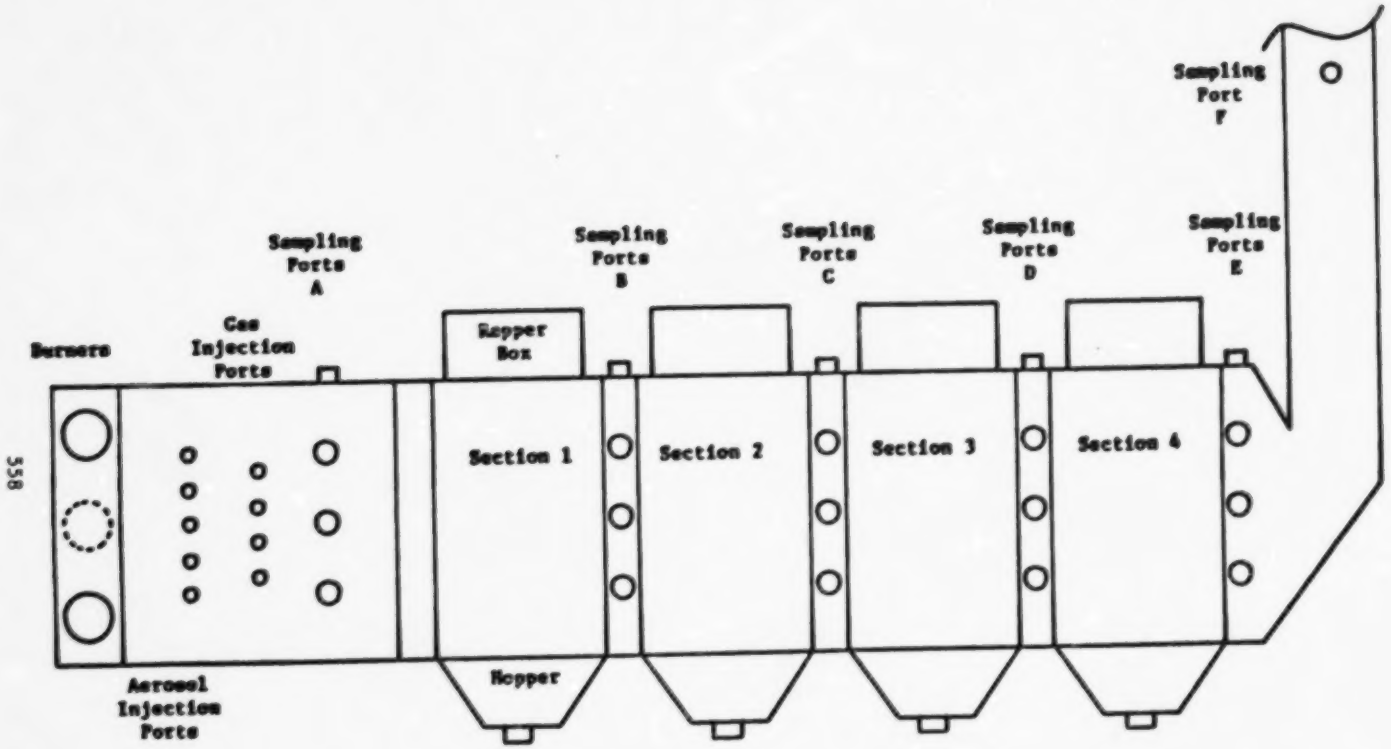

Figure 1. Diagram of pilot-scale ESP.

A sketch of the pulse power supply is shown in Figure 3. A capacitor in the primary of the 1:50 step-up transformer is charged to a voltage V_c which determines the pulse amplitude. The SCR switch is triggered by a timing circuit which determines the pulse repetition rate, and the capacitor is connected to the pulse transformer for one cycle of primary current. The primary capacitor discharges during the first half cycle of the primary current and recharges during the second half cycle.

The output pulse was capacitor-coupled to the corona discharge electrode system. A dc bias voltage, which was variable from 0 to 60 kV, was added to the pulse voltage through a blocking diode. Therefore, the pulse power supply permitted independent control over peak and average voltages.

For these experiments the pulse height and pulse rate were adjusted to give the highest allowable current density at the plate that did not give rise to sparking or back corona. The dc bias voltage was set below the corona onset voltage. The exact conditions depended on the dust resistivity and are given later.

The aerosol used for the experiments was fly ash which was redispersed using sandblast guns fed with a vibrating screw feeder. Previous experience has shown that this is an excellent method of producing aerosol. The resistivity temperature curve for the fly ash is given in Figure 4.

The hot-side evaluation was conducted on a full-scale hot-side ESP at the Lancing Smith Station of Gulf Power. This unit is fully described by Puille et al. (3) The two pulse power supplies evaluated at Lancing Smith were very different in concept. One, supplied by Buell, used a fairly long duration pulse, and the other, supplied by Research Cottrell, used a very short pulse. Additional details on this system are given by Puille et al.

Measurement Apparatus

Charge versus particle diameter measurements were made both in the pilot plant and at Lancing Smith. The charge and diameter of individual particles were determined using a technique and apparatus developed and described by McDonald et al. (4) The technique consists of extracting a sample gas volume from the ESP and directing part of the gas flow into a modified Millikan measurement cell. A single particle is then isolated, and its upward and downward motion under the influence of a uniform electric field can be measured. The particle charge and diameter can be determined by knowing the time required to move up and down a given distance in the electric field.

Figure 5 shows a drawing of the apparatus inserted into an ESP. The gas sample is extracted through 2-in. diameter tubing. Because the technique is limited to particles with diameters less than 4 μm, isokinetic sampling is not required. The tubing leading to the test chamber contains a butterfly valve which controls the flow of aerosol into the test chamber. The valve is opened when a sample is acquired and then closed while the measurements are being made. When the valve is open, the pump is turned on, and an aerosol sample is obtained. When a sufficient number of particles are in the measurement cell,

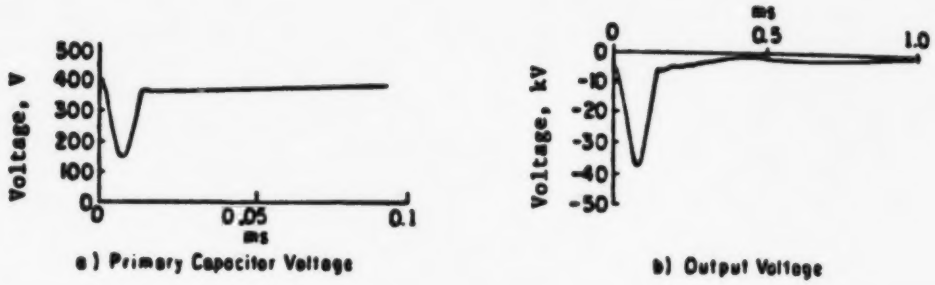

Figure 2. Pulse power supply waveforms.

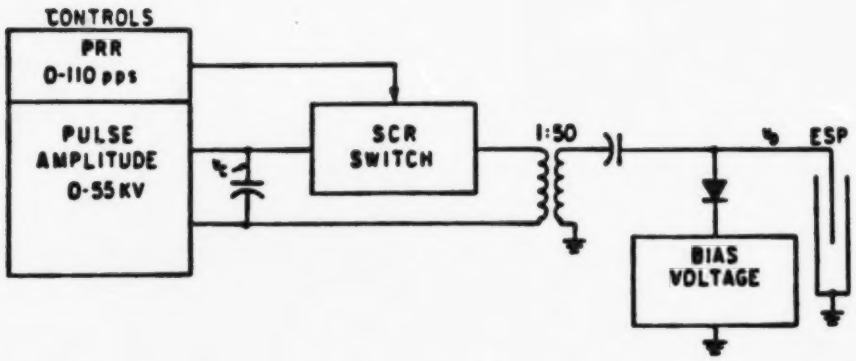

Figure 3. Pulse power supply circuit.

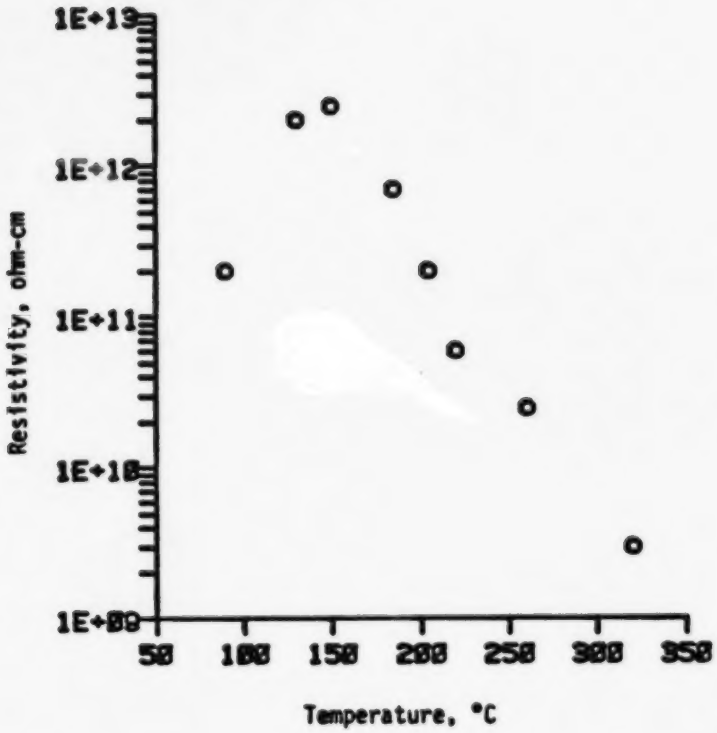

Figure 4. Resistivity vs temperature for redispersed fly ash.

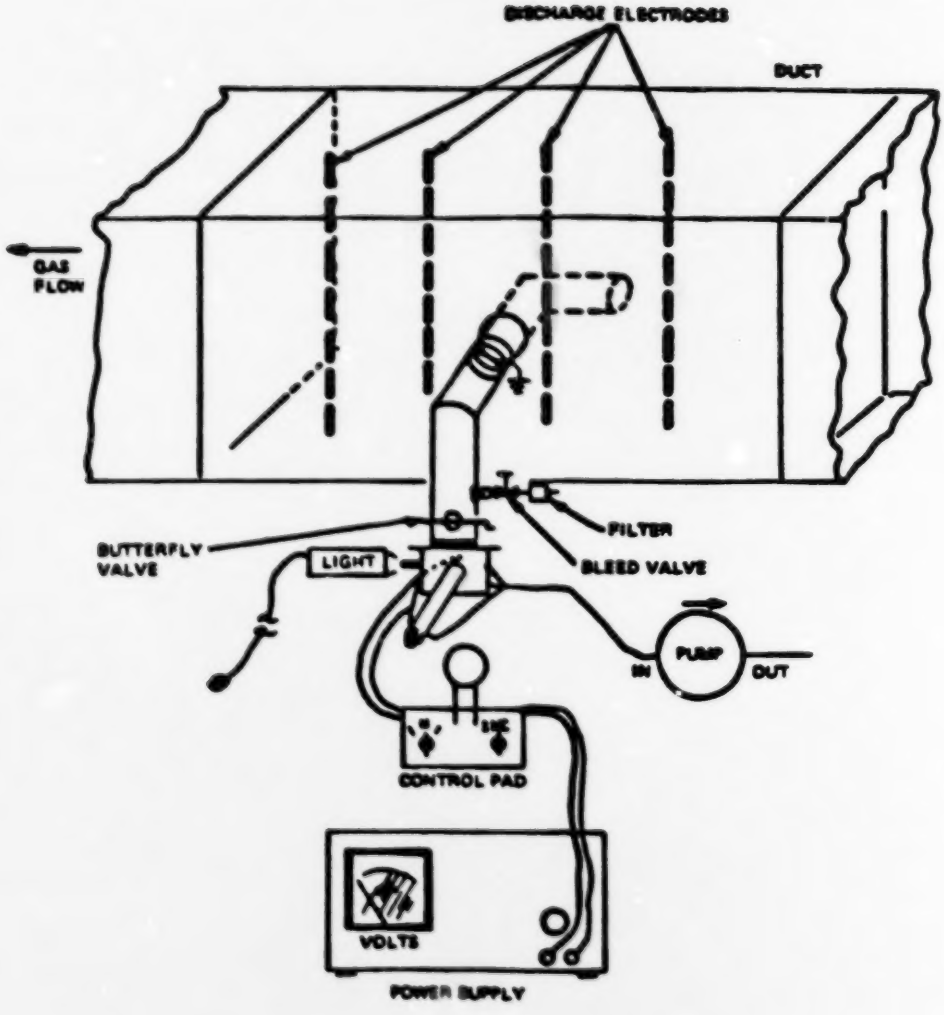

Figure 5. Experimental apparatus for measuring the diameter and charge of particles.

the pump is turned off, and the valve is closed. A very short time after the valve is closed, the motion of the particles is controlled solely by the gravitational field, viscous drag, and the electric field in the measurement cell.

Measurements are made only after all motion due to the gas flow has ceased.

After the particle motion due to gas flow has ceased, the time required for an individual particle to travel a known distance up and down in the electric field is measured. Typically the up and down times for a single particle are determined 3 to 4 times. A new particle is then selected, and the process is repeated. Eventually, the particle concentration in the cell becomes very small, and a new sample is obtained.

Data from the Millikan experiment are reduced on a TRS-80 microcomputer. The computer calculates the particle charge and diameter for each measurement.

Efficiency as a function of particle diameter was determined using cascade impactors. Overall mass efficiency was determined by mass filters.

Test Plan

The pilot plant experiments were designed to provide data on particle charge as a function of particle diameter for dc and pulse under three conditions of electrical resistivity of the dust: low resistivity (2 x 10^{10} ohm-cm), moderate resistivity (2 x 10^{11} ohm-cm), and high resistivity (2 x 10^{12} ohm-cm). The electrical resistivity was varied by changing the operating temperature of the ESP. The low resistivity runs were made at ambient temperature (23°C), the moderate resistivity runs at 218°C, and the high resistivity runs at 150°C.

The high resistivity runs were made with matched current densities at the plate. The current density was about 5 nA/cm^2. Operation above this current density resulted in back corona and poor performance for both pulse and dc. It was found that stable operation at this current density allowed both the pulse and dc to operate in optimum fashion.

The moderate resistivity runs were made again at matched current densities at the plate. The exact current density to use was determined by adjusting the pulse height and pulse rate to give the lowest reading on the PPV. The current density at the plate for this case was 15 nA/cm^2, which was found to be the best operating point for the dc also.

The low resistivity experiments were conducted to determine if pulsing significantly affected the charge on particle either due to the high pulse voltage or due to the pulse of ions produced by the pulse. Consequently, the experiments were conducted at low current densities similar to those used in the high resistivity experiments. By conducting the experiments with low resistivity dust, it was possible to compare the effects of pulsing without the confusing factors of back corona that existed at higher resistivities.

It was quite easy to operate the pulser at the desired current densities for all resistivities. The dc was extremely difficult to operate at the desired current density for the high resistivity case. Even with extremecare, the dc tended to go into back corona unpredictably. Whenever the dc went into back corona, particle collection was reduced. The effects on particle charge are discussed later.

Another set of pilot plant experiments were run in cooperation with Denver Research Institute (5) to determine the collection efficiency of the ESP for both pulse and dc energization. These tests were conducted at 150°C and with a resistivity of about 2×10^{12} ohm-cm. Although an attempt was made to avoid back corona with the dc, it was impossible to completely avoid back corona.

The hot-side evaluation was conducted with moderate sodium conditioning as described by Puille et al. (3)

Results

The results of each of the tests are discussed in detail below. The first part of the discussion is for the pilot plant results.

High Resistivity Tests

The results for the high resistivity runs are shown in Figure 6. The most striking feature of the data is that there is no difference between the charge on the particles under conditions of pulse and dc energization of the ESP. The charge on the particles is in very good agreement with the charge predicted by a model based on the sum of the charging rates due to diffusion and field charging.

It is important to note that the results shown in Figure 6 are the charge on those particles that have charge. Whenever the dc went into back corona, significant numbers of uncharged particles were observed. But even under these conditions, those particles that had charge were charged to the expected values. This behavior is consistent with the idea that the dc current density under conditions of back corona is very non-uniform. Consequently, particles are randomly exposed to areas of current or no current. Particles that are exposed to current are charged as expected; particles that are not exposed to current are not charged.

All particles for the pulse charging experiments were charged all of the time. This is consistent with the data collected earlier that showed that the current distribution at the plate was very uniform under pulsing conditions. Thus, all of the particles are exposed to charging current.

The particle charge data that show that the particle charge is the same for both dc and pulse are consistent with particle collection data which show that, when the dc is operated at low current density and out of back corona, the collection efficiency of the ESP is essentially the same for both pulse and dc. (See Table 1.)

The main value of the pulse power supply appeared to be that it allowed stable operation for long periods of time with the high resistivity dust. Such operation was not possible with the dc. It should be

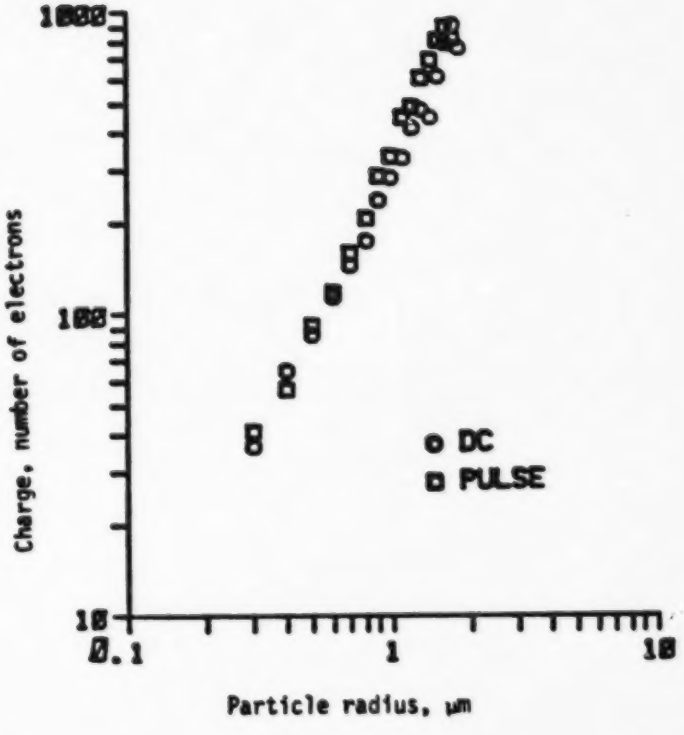

Figure 6. Charge vs radius for high resistivity (temperature - 150°C).

Table 1. COMPARISON OF PULSE, DC WITH HEAVY BACK CORONA AND DC WITH SLIGHT BACK CORONA

Condition[a,b]	Average Penetration, %	No. Tests	Deviation (σ)
dc with heavy back corona	0.224	11	0.0335
dc with slight back corona	0.178	3	0.0103
dc with no back corona	0.160	1	---
Pulse	0.155	7	0.0155

[a]Pilot plant tests with fly ash resistivity = 2×10^{12} ohm-cm.
[b]Inlet dust concentration approximately 1.78 g/m^3 (0.8 gr/ft^3)

emphasized that, as soon as the dc was allowed to operate in back corona, the particle collection efficiency of the ESP dropped, and significant numbers of uncharged particles were observed.

An example of the benefit gained by the control offered by pulse power is shown in Figure 7. It was impossible to control the dc for the entire period required to obtain mass and particle size data; whereas, it was always possible to control the pulse. Consequently, the dc data were collected under conditions of back corona intermixed with conditions of no back corona.

Moderate Resistivity

The results of the moderate resistivity experiments are shown in Figure 8. Again note that there is no significant difference between the dc and pulse data. The standard deviation for the particle charge at a given particle diameter is about 25 percent, as was the case for the high resistivity data.

These particle charge results are consistent with the measured collection efficiency of the ESP, shown by Figure 9 which is a plot of penetration (1 minus efficiency) versus particle diameter. There is no significant difference between the data for dc and pulse.

In this case there was no benefit to pulse power even as a control system. Stable operation was possible for both dc and pulse under these conditions.

Low Resistivity Runs

As mentioned, the low resistivity runs were conducted to see if the pulse affected particle charge. The experiments were conducted at the low current densities used in the high resistivity experiments. The results are shown in Figure 10. Again, note that there is no difference between the dc and pulse data.

Denver Research Institute Experiments

The Denver Research Institute (DRI) experiments were conducted in the IERL-RTP pilot plant. The fly ash used was the same as that used in the IERL-RTP experiments discussed above. The primary measurement in the DRI experiments was charge-to-mass ratio. The results of the charge-to-mass ratio experiments and mass penetration are shown in Table 2. Note that the charge-to-mass ratio for pulse is much higher than the charge-to-mass for dc.

These data show much more of an enhancement due to pulsing than do the IERL-RTP data. During these tests, as in all of the pilot plant tests, it was impossible to avoid operation in back corona with dc energization for long periods of time. Therefore, the dc data represent dc charge-to-mass under conditions of moderate to severe back corona.

The high charge-to-mass ratio for pulse energization is probably due to the uniform current distribution that pulsing gives. Note that

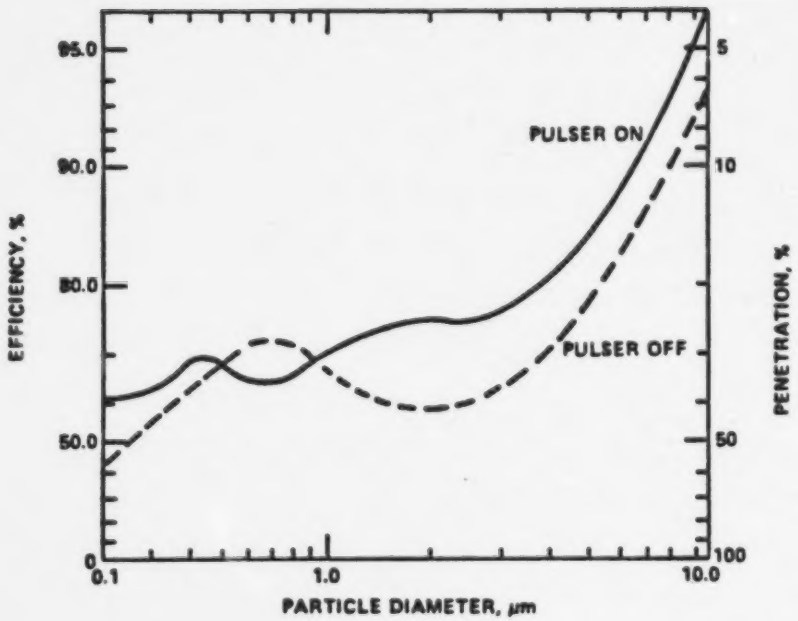

Figure 7. Fractional efficiency data from IERL-RTP pulse energization tests.

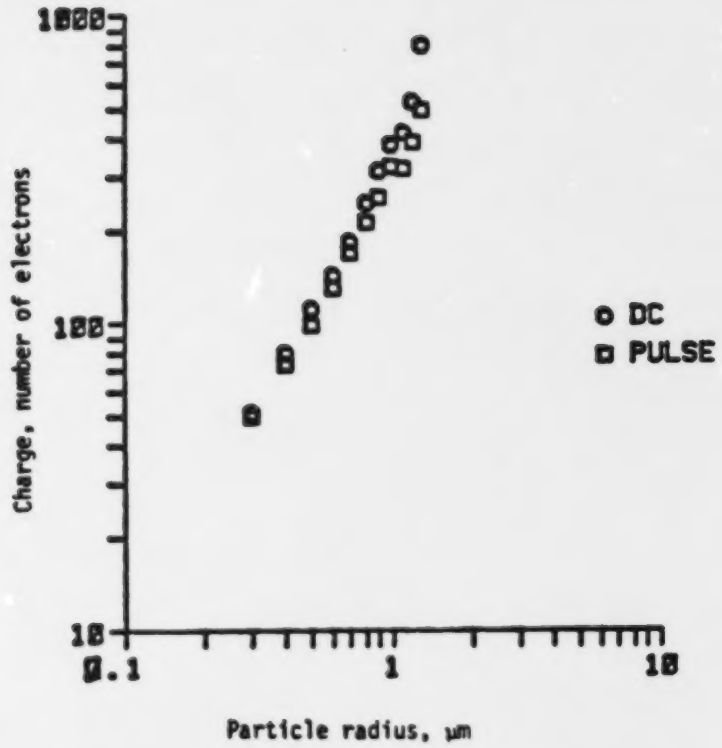

Figure 8. Charge vs radius for moderate resistivity (temperature - 218°C).

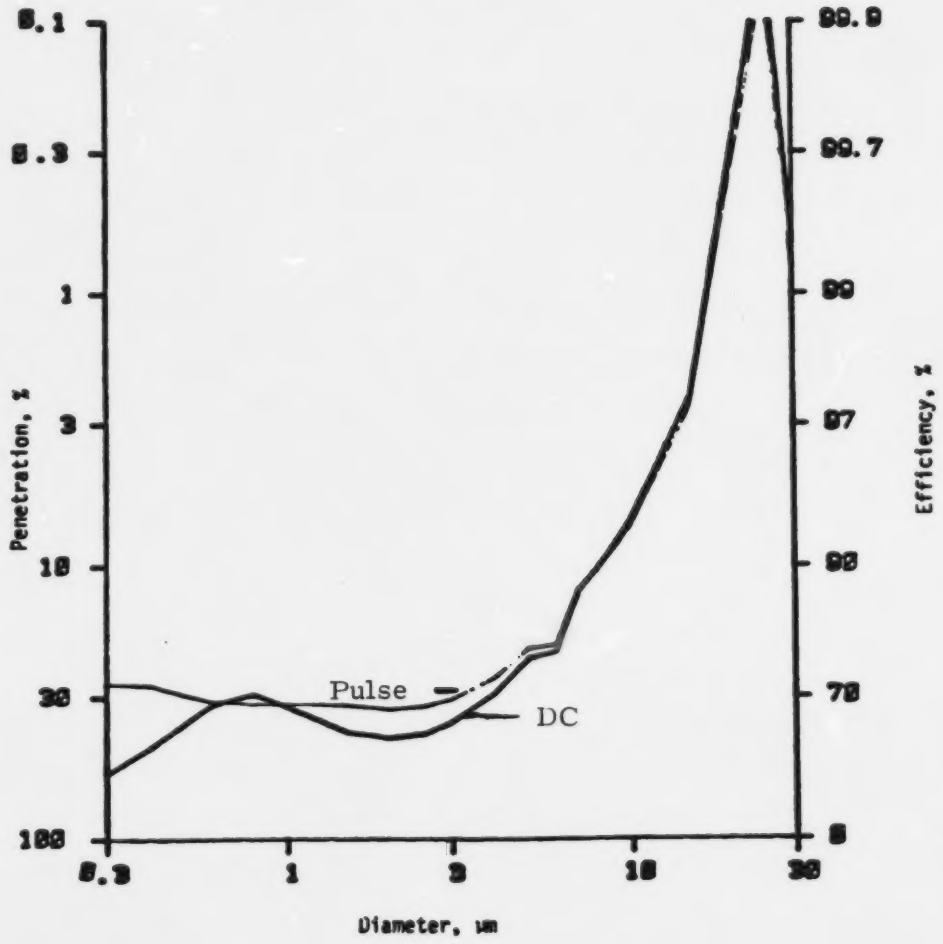

Figure 9. Penetration vs particle diameter for moderate resistivity.

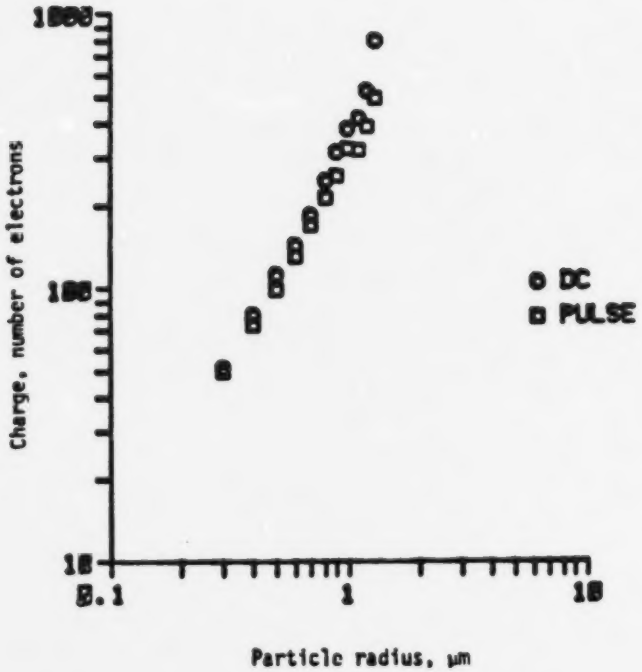

Figure 10. Charge vs radius for low resistivity experiments (temperature - 24°C).

Table 2. RESULTS OF DRI EXPERIMENTS

Parameter	Test 1	Test 2	Test 3
Mass mean particle diameter (d_g), μm	4.9	4.9	4.9
Geometric standard deviation (σ)	3.0	3.0	3.0
Pulse voltage (V_p), kV	60	60	---(dc)
Average dc voltage (V_A), kV	20	15	27.6
Current density (j), nA/cm^2	8.4	7.6	8.9
SCA, s/m	21	21	21
Charge-to-mass ratio (Q/M), C/g	19.6	17.6	6.0
Penetration, %	0.118	0.115	0.248
Resistivity, 10^{12} ohm-cm	2	2	2

in the IERL-RTP runs, significant numbers of particles had no charge when the dc operated in back corona. This was due to the extremely non-uniform nature of the current distribution under back corona conditions.

Hot-Side Tests

Because the results of the Lancing Smith experiment are discussed in another paper, only the results are presented here. The particle charge versus particle diameter is shown in Figure 11. There is a slight improvement in particle charge for some particle diameters.

The particle collection efficiency as a function of particle diameter is shown in Figure 12. Particle collection efficiency is biased for the large particle diameters.

Economics

Although it is hard to obtain good cost data on pulse power supplies, the best estimates are that the use of pulse power will increase costs of an ESP by between \$20 and \$50/m^2 of collector area. These cost estimates can be used to set the bounds of collector plate area reduction that must be achieved with pulse power for its use to be economically justified. Table 3 shows the cost comparisons of conventional dc and pulse for 0, 10, 20, and 50 percent plate area reductions and pulse power costs of \$20 and \$50/m^2 of plate area. The costs were estimated using a cost model described by Viner and Ensor (6). The cost projections show that pulse power may be a marginal technology.

Discussion

The main conclusion drawn from these data is that there is no difference between the performance of an ESP using either dc or pulse power if the ESP is not allowed to go into back corona. As soon as the ESP operates in back corona (most likely with dc), particle collection efficiency decreases, and significant numbers of uncharged particles are found. This conclusion (i.e., operation in back corona is bad) is not new but is often forgotten.

The main advantage of using pulse power supplies is that good control of the electrical operating conditions of the ESP is possible, even when dusts with high electrical resistivity are being collected. Such good control is often not possible with dc. The value of good control should not be neglected: that pulsing permits control of the operation of an ESP is significant.

The improved charging noted in the hot-side experiments may be due to increased free electron charging. It seems reasonable to assume that the intense short high voltage pulse would produce more free electrons than conventional dc.

Since the main advantage of pulse power seems to be better control, it may be more cost effective to develop improved dc control systems instead of pulse power.

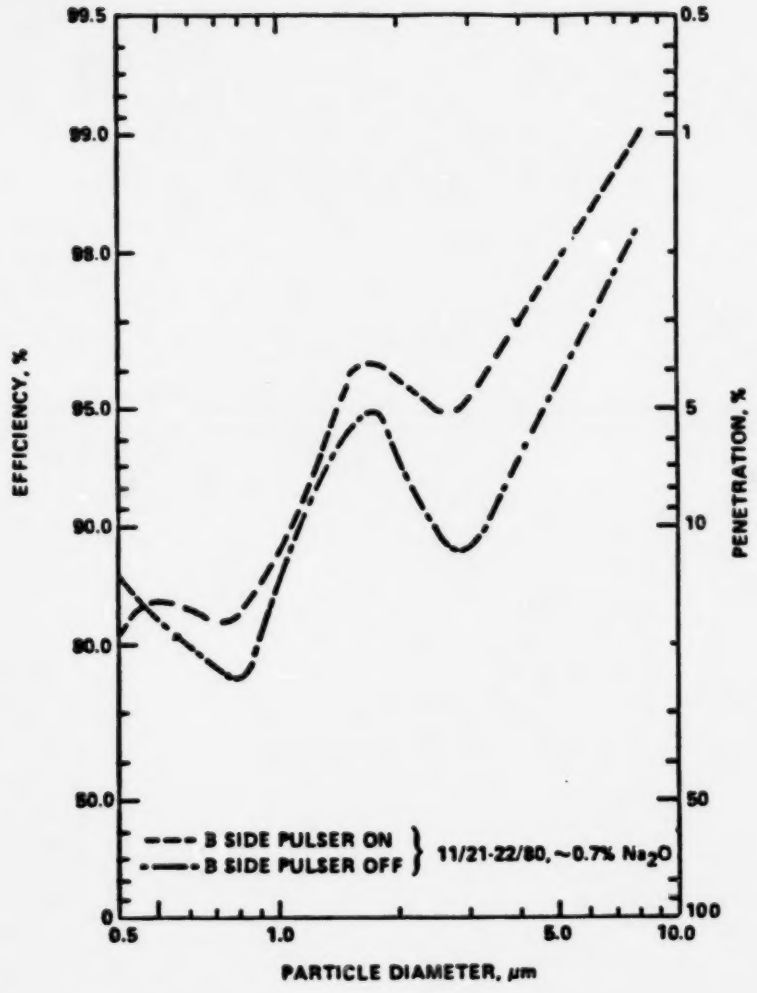

Figure 11. Fractional efficiency of B-side ESP--pulser on and off.

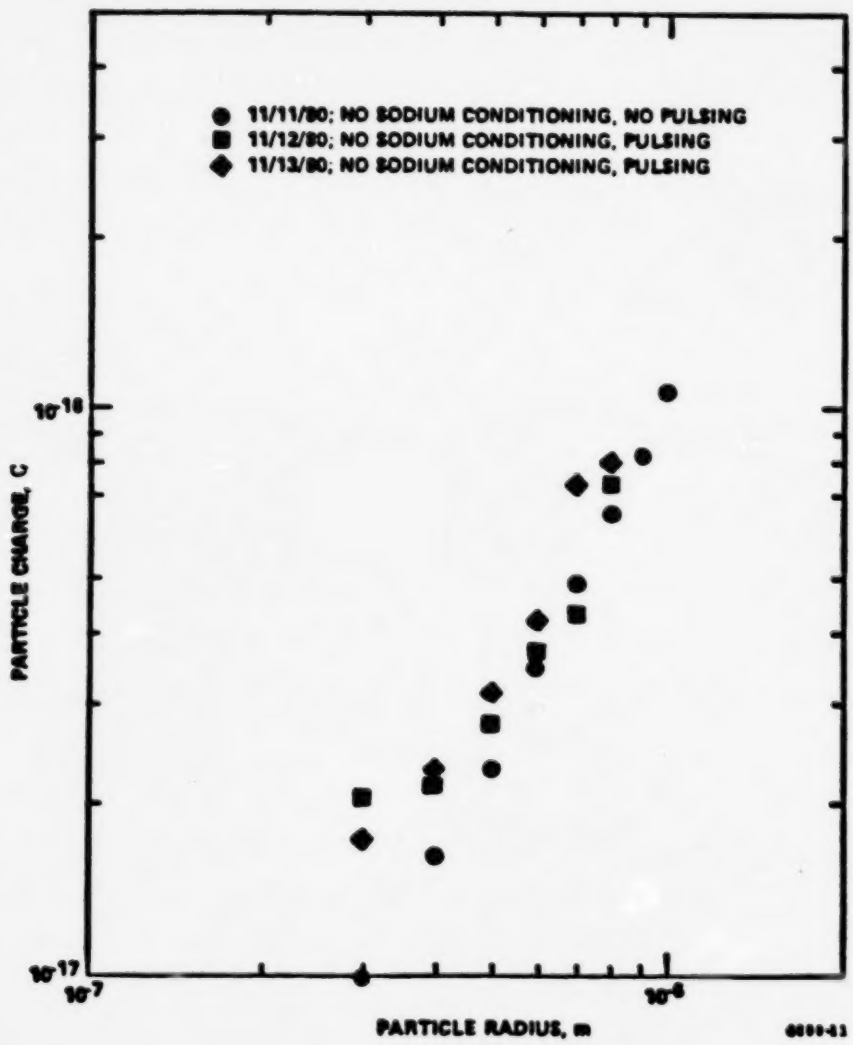

Figure 12. Comparison of particle charge with and without pulsing on the B-side with no conditioning.

Table 3. COST COMPARISON OF CONVENTIONAL AND PULSE POWER 500 MW PLANT

Assume SCA = 158 $m^2/m^3/s$ (800 ft^2/1000 acfm) Conventional ESP

% Reduction	SCA $m^2/m^3/s$	Cost @ $20/m for pulse	Cost @ $50/m for pulse
0	158	$33,000,000	(Conventional ESP)
10	143	$33,400,000	$36,000,000
20	124	$30,000,000	$33,000,000
50	79	$23,000,000	$27,200,000

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